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APPRAISING FOREST FUELS: A CONCEPT

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ABSTRACT

Management of our wildland resources requires knowledge of the vegetative load or fuels in the forest. This paper defines the elements making up fuel appraisal and offers a concept for appraising fuels based on current information. An example is presented utilizing data for inland Douglas-fir (Pseudotsuga menziesii).

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KEYWORDS: fuel appraisal, forest fuels, fire hazard

KNOWLEDGE REQUIREMENTS

To develop plans for fuel or fire management, we must know how to characterize, inventory, and appraise fuels. Countryman (1969) stated that we must regard vegetation as fire areas--as a fuel--and learn to evaluate it in terms that relate to fire behavior. Countryman (1969), Wilson and Dell (1971), and Dodge (1972) are a few of the many researchers who have noted that we cannot really control the weather or shape the topography, but we can and do influence the quantity and character of wildland fuel. Therefore, we must learn to assess wildland vegetation as fuel and appraise potential fire behavior in terms that are meaningful to wildland management personnel. Research on fuel characterization, inventory, and appraisal should be directed toward this objective.

These descriptions of fuels include evaluations of fire behavior characteristics in given fuel situations that indicate the ability of a fire to meet a given objective

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or the probability of the fire exceeding certain level of tolerable activity. Several frames of reference must be used:

1. Situations that relate to short-term change (i.e., the potential as the fire season progresses).

2. Situations that relate to long-term change (i.e., the hazard associated with stand age and successional changes).

3. Situations resulting from interferences with the normal processes of the ecosystems (i.e., what is the fire potential and fuel hazard consequences of a given management action?).

Fire research findings must be combined with other research fields to understand the formation and life history of fuels, fire potential changes, consequences of fire occurrence, and formation of new fuels after a fire. The fuel generation on a unit is the net result of producers and decomposers within the ecosystem and the alterations that man imposes.

FUEL CHARACTERIZATION

The basic data needed to develop a comprehensive understanding of fuel characteristics can come from many published sources: range habitat, silviculture, watershed, wildlife habitat, and timber management. One major aspect of fuel characterization relates to the intrinsic biological and physical properties of a vegetative type. The size class distribution of branchwood for trees and brush is an example. Other examples include the mean size within a size class, the weight distribution of foliage and branchwood, and the fuel load for grasses and brush as related to percent cover and number of stems per acre.

Another major aspect is the growth response of the species or timber type to site and climate in which it exists. This aspect must consider how proportions of live and dead material change with time, but such information is not available. Species response to site and age in tree height, crown weight, d.b.h., and other physical properties has to be established. If fire spread is to be mathematically modeled, then values for fuel density, heat content, and mineral content must be determined. Once determined, these functional relationships can become part of a data source library that can be used to quantify measurements made during the fuel inventory or to model fire behavior.

FUEL INVENTORY

Nationwide, we have only general knowledge of fuels. Knowing fuel quantity and character on a regional basis requires that fuels be inventoried regionally. These inventories would utilize the relationships determined during the fuel characterization process and the most efficient measuring techniques. Then we can have quantitative fuel and vegetation information for interpretation. Interpretation will have to incorporate (1) experienced judgment; (2) comparison to referenced fuel and vegetation; and (3) mathematical models of fire phenomena. An experienced fire manager may be able to look at fuel load and species type and predict fire behavior. Another manager may require mathematical modeling to determine what the behavior may be. The intent is to provide tools that will assist the manager at whatever level he desires.

Before adopting inventory procedures, it is necessary to thoroughly understand the modeling needs in addition to recognizing the requirements and limitations of subjective or comparative interpretation. This demands a new perspective on present-day resource inventory, particularly the need to include dead vegetative material in the inventory. Brown (1971) directed his work toward this need and showed that fuel inventory procedures are compatible with timber and range inventories. Inventory procedures are being used for fuels in the Rocky Mountain area on several National Forests and for the White Cap

Wilderness Fire Management Study in the Selway-Bitterroot Wilderness area (Aldrich and Mutch 1971). These inventory procedures indicate the tons per acre of dead vegetation by size classes, the tons per acre of standing living vegetation by size class, the percent cover of rotten wood, number of trees and dead snags per acre, stand height, tree age, and several other items.

FUEL APPRAISAL

During appraisal, the information on fuel characterization is merged with field inventory data to provide the land manager with an estimate of fuels within a stand. The manager makes estimates of the fire potential or can utilize mathematical models to describe the various fire potentialities of a site. Much thought must go into deciding fire potentials that should be included in fuel appraisal. Although some fuel appraisal has been provided with the National Fire-Danger Rating System (NFDRS) and its broad fuel models, we need to extend our capabilities. At the present time there may be as many elements of fuel appraisal as there are individuals assessing fire hazards. One of the greatest challenges existing in development of a fuel appraisal system is adequately describing the fire hazard. Elements to be considered would include the following:

1. *Rate of spread*: Expressed in a standard spread rate such as chains-per-hour or is divided by the maximum spread rate (as in the NFDRS).

2. *Rate-of-area growth*: Expressed as perimeter length or as acres-per-hour, growth rate would assist in determining the type and amount of suppression forces needed. A reference size such as 10 acres at the end of the first hour could be the relative measure to indicate the speed of attack needed.

3. *Fire intensity*: This element reflects the difficulty of direct attack and may be keyed to the effectiveness of various indirect attack methods. The energy release rate may be referenced to some energy level associated with the onset of conflagration behavior. Flame length can be an effective measure, particularly when compared to some basic standard such as the average man's height. This allows relating to an element of personal danger.

4. *Crowning potential*: The capability of ground fuels to generate flames high enough to reach the tree crown may be equated to the distance to the crown base. Ladder fuels and dead branchwood in the crown are recognized as factors that affect the probability of crowning. In addition to measuring crowning potential, it may be possible to expand fuel appraisal to include assessment of scorching.

5. *Firebrand potential*: This would provide an estimate of a fire's capability to produce and cast burning embers into the convection column and the ambient wind's ability to carry the embers. In order to determine if any of the embers will reach the ground still burning, we need to estimate gas velocity and inventory the fuels well enough to identify firebrand material by size class and weight. Considerable research is needed to develop the necessary base information.

6. *Spot fire potential*: This factor would be similar to the ignition component of the NFDRS but the fuel most likely to be ignited must be identified. This element of fuel appraisal would compare the time required to ignite fine fuels with the burning time of the most probable firebrand. Additional research will be necessary to determine the accuracies required.

7. *Fire persistence*: This element would indicate the potential mopup problem and the probability of holdover fire. The percentage of area covered with punky and rotten material and rate of spread by glowing combustion may be developed to represent the time required for the fire to reach a more flammable fuel. This hazard will require extensive research to provide an adequate index of the mopup job or the problems with fires

that are dormant for hours or days and, in some cases, weeks. Additional study of the latent stage of a fire (the probability of holdover fires occurring) needs to be done (Taylor 1969).

These factors can be useful elements within a fuel appraisal system; however, each element must be considered on an individual basis related to the site. After individual judgment, a merging of the fuel appraisal factors must be made by the manager to obtain the total fire problem of the site. These fire hazard elements are only some of the possibilities. Suggestions on other hazard elements that should be considered are invited.

RELATED CONSIDERATIONS

A fuel appraisal system must accommodate the weather variations across the country so objective comparisons can be made of similar fuel situations in different weather regimes. Fire weather is a variable we cannot control. It also is one of the dominant factors of the fire potential for any given day. The publication "Fire Weather" (Schroeder and Buck 1970) provides a general view of the United States by fire climate regions and points out that fire-danger rating integrates the weather elements with other factors affecting fire potential. The NFDRS (Deeming and others 1972) builds the danger rating indexes from fire-danger station readings of temperature, cloud cover, precipitation, relative humidity, and windspeed. NFDRS ratings are relative and not absolute. The fuel models developed for the NFDRS were general models to reflect the trends in expected behavior of a potential fire. A fuel appraisal system will be a supplement to the NFDRS by quantifying fuels that exist upon a given unit of land. Changes in the amount of fuel available to the fire due to weather changes should be recognized in the appraisal system.

The capability of firefighting forces to maneuver on the fireline and the fire's resistance to control efforts must be considered in fuel and fire management plans. Because many suppression techniques are available and rates for fireline building vary, resistance to control may need to be assessed separately from fuel appraisal even though fuel inventory information is used. Storey (1969) noted that the assumed production rates for a given type of fireline construction were found to vary widely among the Forest Service Regions and the differences could not be explained on the basis of different soil, fuel type, or other conditions. In addition, he noted that productivity data for various types of firefighting forces are available for only hand crews and bulldozers although nine forms of forces were recognized.

Guides are only as good as the conceptual design and the input data. If we are going to use national fire-danger rating and desire national fuel appraisal, it also makes sense that we have a measure for national fireline productivity. I anticipate that future use of computer techniques and mathematical modeling for fire-danger rating, fuel appraisal, and fireline productivity will not be used for dispatching, but that experienced judgment will be the best and fastest way to estimate tradeoffs under actual situations. However, planning on a day-to-day basis or a year-to-year basis can make use of these systems if they are based on objective, quantitative data.

A CONCEPTUAL APPROACH

In forest research, we now have enough data to begin fuel appraisal. The concepts that have been expressed in this paper can be illustrated in an example with inland Douglas-fir (*Pseudotsuga menziesii*) represented by site index of 60 at 50 years of age. The fuels being appraised will be those less than 2 inches in diameter in the tree canopy.

The following equations were assembled to allow assessing the fuel changes in the specified fuel type over time.

$$H_T = 91.57[1 - 1.153 \exp^{-0.0255A}]^{1.0608} = \text{tree height, ft.}$$

where

A = age, years

$DBH = \exp[1.317 \ln(H_T) - 2.688]$ = diameter at breast height, inches. The above are after the work of Brickell (1968).

$h = 4.0 + 2.60\ DBH$ = crown length, ft.

$$W_c = \frac{[(DBH)(h)]^{1.0108}}{3.811} = \text{crown weight/tree, lb/tree, ovendry weight.}$$

These equations were determined by Fahnestock (1960) or were modified by him after Storey and others (1955).

$C_w = 5.031 + 1.423(DBH)$ = maximum crown width, ft.

This equation is cited by Bella (1971), after Newnham,[2] and may represent coastal Douglas-fir more accurately than inland Douglas-fir.

The work by Storey provided total crown weight and the portion that is in foliage and branchwood. Consolidating these data with Fahnestock's provides the mean size within each size class and the portion of the total fuel load in each size class.

The characteristic distribution of foliage and branchwood by size class is shown in figure 1 and was acquired through the works of Fahnestock (1960) and Storey and

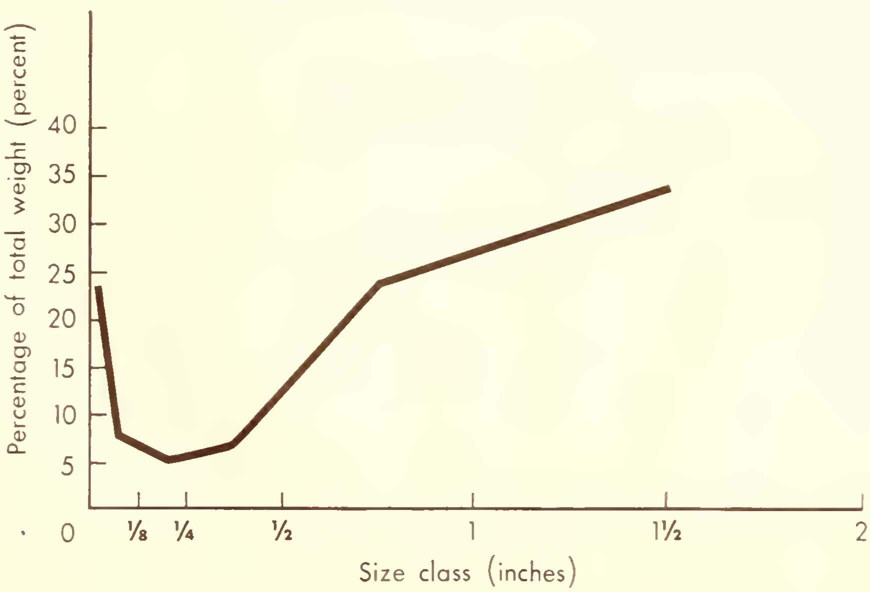

Figure 1.--Percentage of total crown weight by size class for material under 2 inches diameter (inland Douglas-fir).

[2] R. M. Newnham, Unpublished thesis, University of British Columbia. 1964.

others (1955). Other works, including theirs, show that a number of timber types have a similar characteristic. Data collected on Engelmann spruce (*Picea engelmannii*), grand fir (*Abies grandis*), Douglas-fir, and western hemlock (*Tsuga heterophylla*) indicate that these timber types have general characteristics of distribution that could be described by one equation. This characterization of the distribution of fuel by size is needed for slash considerations or crown fire estimates.

Using the data and equations described we can calculate the number of even-aged trees on a site, the total crown weight or unit area fuel load, and the d.b.h. at any age. An assumption (any number of assumptions are possible) is made that this stand is being managed or is adjusting itself to maximum utilization of space and light and that the stand is always at 100-percent crown closure. With these assumptions and the equations cited above, stand properties are illustrated in figure 2. The number of trees per acre is determined by knowing crown width, calculating the area for each tree crown, and determining the number of tree crowns per acre. This information, then, with the crown weight per tree, gives the tons per acre of material under 2 inches diameter.

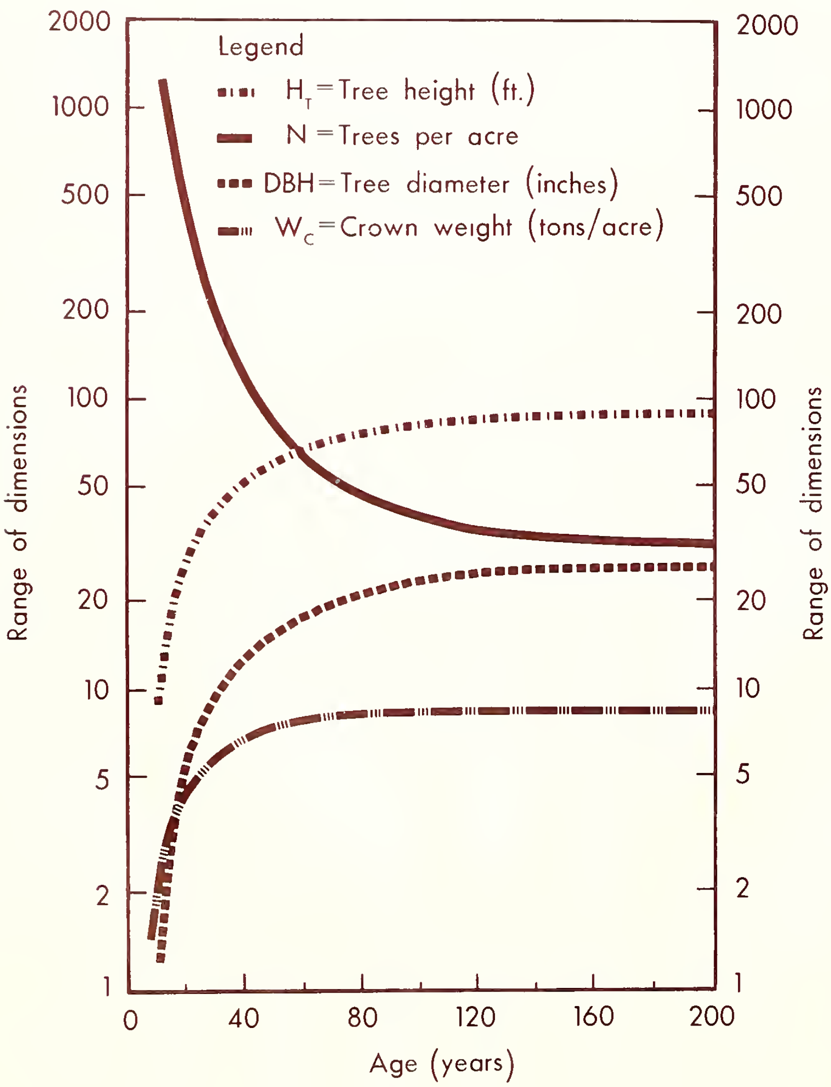

Figure 2.--Inland Douglas-fir stand physical properties change with time on a site index of 60 at age 50 years. Site equations and curves by Brickell (1968) were utilized.

Figure 2 shows that in a crop of trees the amount of dead material either on the ground or standing changes with time. In this example, the number of trees is continually decreasing with age, which suggests that a number of trees are dying in each time interval. These trees and their crown load contribute to the fuel load that is underneath this stand. This fuel is estimated by first determining the number of trees lost per acre between two age classes. Second, this number of trees per acre is multiplied by the crown weight per tree to obtain the fuel load gain per acre for the time period used. To be realistic, the decay rate of this material must be estimated.

Decay rates have been determined for downed foliage and branchwood. A simplifying general concept is that this decay rate, like many other natural rates, is exponential, as shown in the following equation:

$$W = W_0 \exp\left(\frac{-t}{T}\right) = \text{Tons/acre}$$

where

W_0 = initial fuel load, tons/acre

T = decay constant, years

t = time since start of decay, years.

The work by Childs (1939) on decay of slash in the Douglas-fir region provides an estimate of the decay constant. For Douglas-fir slash and western hemlock, in stands referred to as Douglas-fir type, the decay constant (or time to lose 63 percent of the volume) ranged from 15 to 29 years. In this paper a decay constant of 20 years is used to demonstrate the appraisal technique.

Changes in fuel load were estimated at 10-year intervals, adjusted for decay, and then summed. Dead crown fuel accumulated underneath a Douglas-fir stand is shown in figure 3. Accumulation peaks about 30 years after stand establishment because of the

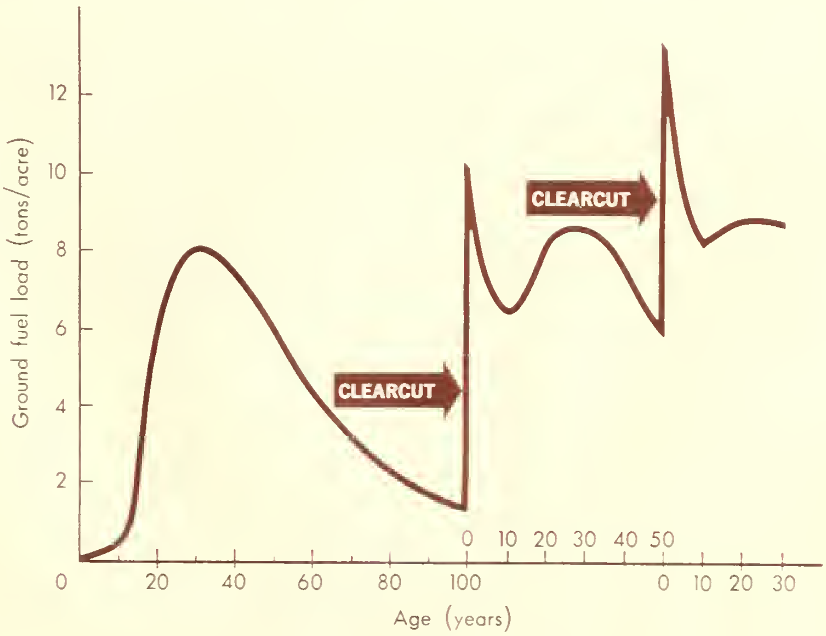

Figure 3.--Changes over time in estimated crown-contributed ground fuels, less than 2 inches in diameter, under an even-aged Douglas-fir stand due to natural thinning or timber harvest.

large change in number of trees per acre between the 20- and 30-year points and the 30- to 40-year points. In addition to knowing the quantity of fuels less than 2 inches in diameter, we also need an estimate of the understory fuel components before we can establish fire behavior or fuel appraisal factors. Estimates of the fuel load, depth, and surface-area-to-volume ratio for ground fuel are given in table 1.

Estimates of surface-area-to-volume ratios and fuel depths were obtained from publications by Brown (1970a,1970b) and Lyon (1971). The data generated through this example can be used as input to fire behavior and flame prediction equations such as generated by Rothermel (1972) and Thomas (1963) and utilized by Brown (1972). Weather conditions were applied as part of the fire spread model inputs. Fuel moisture content was set at 4 percent; average windspeed was set at 8 mi/h, which is slightly higher than the average windspeed during the summer in most of the Western United States (USDC Environmental Science Services Administration 1968).

Fuel appraisal concepts are the results obtained by combining the output of mathematical fire simulations with fuel inventory and research data developed for other fire behavior characteristics. For this example we will consider forward rate of spread, flame length, and flame height as our fuel appraisal factors. To determine the relative hazard, a reference is needed for each factor. Based on Forest Service data for the Western United States, the average forward rate of spread is approximately 15 chains per hour. Divide the calculated forward spread by this factor. For flame length, consider the equating factor as 6 feet (an average man's height), which relates to the personal danger involved in working close to the fireline. For measuring crowning potential, reference flame height against the distance to the base of the live crown. Using the data presented in table 1, the three factors were evaluated. Results, presented in table 2, provide some insights into the effects of cultural treatments, fuels, consequences, and some aspects of fire behavior needing consideration at various periods in the life cycles of the site.

Table 1.--*Estimate of ground fuel properties essential to establishing fuel appraisal factors in a Douglas-fir stand*

Age (years)	Ground fuels	Crown dead fuels[1]	Total fuel	Fuel depth	Average fuel diameter	Average surface-area-to-volume ratio
	- - - - -*Tons/acre*-	- - - -		*Feet*	*Inches*	*Ft^2/ft^3*
10	1.0	0.3	1.3	1.5	0.027	1,750
30	.5	8.0	8.5	.5	.120	400
50	.5	5.8	6.3	.4	.137	350
100	.2	9.9	10.1	2.5	.077	622
120	1.5	8.0	9.5	1.8	.137	350
140	.2	7.3	7.5	1.5	.137	350
150	.2	12.8	13.0	3.0	.077	622

[1]Material is assumed to fall to the ground in the last 10 years.

Table 2.--*Fuel appraisal factors for a Douglas-fir site and timber stand at various ages. Factors greater than 1.0 represent an increase in hazard whenever wind reaches 8 mi/h and fuel moisture reaches 4 percent*

Age (years)	Rate of spread factor	Flame length (intensity) factor	Flame height (crowning) factor
10	21.6	4.2	6.4
30	1.4	6.5	1.3
50	1.0	4.1	.6
100/0[1]	12.1	27.7	[2] 5.8/--
120	4.9	12.9	4.6
140	4.1	9.1	1.7
150/0[3]	14.4	39.4	10.3/--

[1]Assumes clearcut at 100 years, followed by regeneration.

[2]Once clearcut, there would be no crown base for flame height to reach. Remaining tree crowns would be scorched or burned out.

[3]Assumes regeneration cut at age 50.

DISCUSSION

The fuel factors in table 2 point out some of the considerations we can make as we plan our management activities. For instance, at 10 years of age fire spread will be high due to herbaceous material (table 1). The flame will not be very intense but it will be high enough to scorch regeneration. At 30 and 50 years of age, both the spread factor and flame height factor have decreased. The flame height factor has decreased because fuel buildup has been too slow to allow flame height to reach the base of the crown. However, the flame length factor peaks at about 30 years when there is a maximum amount of fuel on the ground. The effect of clearcutting the stand is shown at the 100-year point in time. The flame length factor has increased to a high value that reflects the difficulty of fighting fire close to the fireline in slash. At the second cutting in year 50 of the second cycle we can see that spread is significant, as is flame length factor. Fuel buildup is leading to a more and more difficult fire situation. In addition, the flame height factor shows that if we leave seed trees or make a shelterwood cut, flame height will be as much as 10 times the height to the base of the crown, which will result in crown scorch and individual crowning of trees.

SUMMARY

I have presented a general concept for quantifying fuel appraisal that will provide the land manager another decisionmaking tool. I recognize that considerable effort is needed to pull together existing data, identify the missing information, conduct studies, and develop appraisal approaches that will be meaningful to fieldmen. Nevertheless, I think the concept discussed can provide a better base for making plans and decisions for fuels and fire management than we have had in the past. We now need to pool existing capabilities and knowledge to refine and develop a fuel appraisal system that will be universally useful.

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